Behavioural Brain Research 313 (2016) 345–357

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr

Review

The role of the hippocampus in approach-avoidance conflict decision-making: Evidence from rodent and human studies

Rutsuko Ito[a,b,*], Andy C.H. Lee[a,c,*]

[a] Department of Psychology (Scarborough), University of Toronto, Toronto M1C 1A4, Canada
[b] Department of Cell and Systems Biology, University of Toronto, Toronto M5S 3G5, Canada
[c] Rotman Research Institute, Baycrest, Toronto M6A 2E1, Canada

HIGHLIGHTS

- The hippocampus is viewed primarily as a memory and spatial cognition structure.
- There is increasing interest in its involvement in approach-avoidance conflict.
- Accumulation of rodent data suggests the ventral hippocampus plays a key role.
- Recent human work provides convergent cross-species evidence.

ARTICLE INFO

Article history:
Received 10 June 2016
Received in revised form 20 July 2016
Accepted 22 July 2016
Available online 25 July 2016

Keywords:
Hippocampus
Septotemporal axis
Long axis
Decision-making
Conflict
Approach-avoidance
Memory
Spatial cognition
Rodent
Human
Lesion
Functional neuroimaging

ABSTRACT

The hippocampus (HPC) has been traditionally considered to subserve mnemonic processing and spatial cognition. Over the past decade, however, there has been increasing interest in its contributions to processes beyond these two domains. One question is whether the HPC plays an important role in decision-making under conditions of high approach-avoidance conflict, a scenario that arises when a goal stimulus is simultaneously associated with reward and punishment. This idea has its origins in rodent work conducted in the 1950s and 1960s, and has recently experienced a resurgence of interest in the literature. In this review, we will first provide an overview of classic rodent lesion data that first suggested a role for the HPC in approach-avoidance conflict processing and then proceed to describe a wide range of more recent evidence from studies conducted in rodents and humans. We will demonstrate that there is substantial, converging cross-species evidence to support the idea that the HPC, in particular the ventral (in rodents)/anterior (in humans) portion, contributes to approach-avoidance conflict decision making. Furthermore, we suggest that the seemingly disparate functions of the HPC (e.g. memory, spatial cognition, conflict processing) need not be mutually exclusive.

Contents

* Corresponding authors at: Department of Psychology (Scarborough), University of Toronto, 1265 Military Trail, Toronto, Ontario M1C 1A4, Canada.
E-mail addresses: rutsuko.ito@utoronto.ca (R. Ito), andych.lee@utoronto.ca (A.C.H. Lee).

http://dx.doi.org/10.1016/j.bbr.2016.07.039

1. Introduction

An approach-avoidance conflict arises when an organism is both attracted to, and repelled by the same goal stimulus. In other words, the goal is imbued with both positive and negative qualities such that it creates a competition between incompatible motivations and responses [1,2]. The organism's decision to approach or avoid the goal is ultimately dependent on the individual computing the value, likelihood and magnitude of the outcomes and the incentive stimuli associated with the outcomes, and reaching a point of compromise between costs and benefits. For instance, a hungry animal deciding whether to forage for food in a dangerous environment (e.g. due to the presence of a predator or environmental hazards) needs to consider the potential benefits of much needed calorific intake alongside the probability for negative consequences such as bodily harm. Notably, such decisions can often become maladaptive, giving rise to situations in which one response tendency (approach or avoid) may dominate.

Historically, a number of decision-making paradigms have been used to assess the brain regions involved in approach-avoidance behaviour during conflict. For example, non-human animal and human studies using delay discounting (subjects must choose between immediate smaller rewards versus delayed larger rewards), effort based decision-making (choosing between easily attainable rewards vs. working harder to obtain rewards), and gambling-like card-based tasks have demonstrated that the amygdala-medial prefrontal cortex pathway is crucial to decision-making involving uncertainty [3–6]. More recently, however, the hippocampus (HPC), a brain region more readily associated with its role in learning and memory processes [7,8] and spatial cognition [9], has come under increasing scrutiny for its role beyond these two domains, in particular, in aspects of inhibitory response control in situations in which some form of stimulus, motivational or response competition is experienced [10–13]. This work has its original roots in the late 1950s to 1960s, when the HPC was popularly known to play a key role in behavioural inhibition [e.g. 14–18]. Indeed, one influential theory by Gray [19], which was proposed to encompass much of this early research, suggested that the HPC is the driving force of a behavioural inhibition system that is activated in situations of imminent threat to inhibit a movement or an action that could be detrimental to an animal's survival (e.g. a mammal freezing when seeing a bird of prey overhead).

The goal of this review is to examine experimental evidence that has implicated the HPC in approach-avoidance conflict processing. Given the plethora of data that are relevant to this issue, we have decided to focus on rodent and human studies that have directly investigated the role of the HPC in approach and avoidance behaviour, in particular those that have used tasks that pit these two responses directly against each other, for example, via the simultaneous presentation of conflicting valence information. As will be evident later, there is a considerably larger number of relevant rodent studies compared to human studies and as such, while groups of rodent studies will often be summarized, individual human studies will be described in relatively greater detail. In addition to this, although we are aware that approach-avoidance conflict paradigms have been used as a key means to study anxiety and that the HPC has been implicated in a range of anxiety disorders and anxiety characteristics [e.g. 20–25], we will not be considering the entire, vast literature on the relationship between the HPC and anxiety, and will primarily provide more detailed discussion of studies that have sought to understand the neural basis of approach-avoidance conflict processing as a cognitive mechanism, without necessarily drawing conclusions about anxiety disorders. Finally, given that cross-species evidence will be considered, a brief note on anatomical terminology is necessary. There is now substantial evidence to suggest that the HPC should not be considered as a unitary structure but rather, as an anatomically and functionally heterogeneous structure. Considerable work on this heterogeneity has concentrated on the differences along the septotemporal (long) axis of the HPC, with a demarcation of dorsal (septal), and ventral (temporal) regions (dHPC, vHPC) in rodents, and posterior and anterior HPC (aHPC, pHPC) in humans as corresponding regions, respectively [e.g. 20,26–29] (Fig. 1). While caution must be exercised in assuming the existence of functional homology between the rodent and human HPC regions, there is compelling anatomical evidence indicating that the topographical pattern of connectivity between the HPC and subcortical/cortical structures is strikingly similar between the rodent and primate brains [30,31]. For instance, projections from the entorhinal cortex (EC) to the HPC follow a dorsal to ventral gradient in rodents (dorsolateral EC connecting with dorsal HPC, and ventromedial EC connecting with ventral HPC), and similarly, in primates, follow an anterior to posterior gradient [32]. HPC connectivity with subcortical structures exhibits similar topographical gradients in the rodent and human brains, with the ventral HPC and anterior HPC projecting to the medial aspects of the amygdala and nucleus accumbens (NAc shell), and the dorsal HPC and posterior HPC innervating the lateral aspects of the NAc (core), albeit the most dorsal/posterior aspects of the HPC do not project to the amygdala [28,31]. In addition to this, while rodent work has further identified an intermediate HPC section that separates the ventral and dorsal regions [27,33], a similar division has not been commonly made in humans.

2. A brief historical perspective from the rodent literature

The notion that the HPC is involved in aspects of behavioural inhibition, that is, the suppression of responses under conditions of environmental instability, gained momentum in the 1960s after repeated observations that HPC lesions rendered rats unable to inhibit learned approach responses in the face of punishment [34], or in the absence of reward [35]. Many of the early studies utilized discrete trial runway tasks that incorporated an element of approach-avoidance conflict. For instance, in lesion studies by Kimura [14], Isaacson and Wickelgren [34] and Kimble [16], rats were first trained to enter a 'goal box' at the end of a runway that contained food (approach training). Once trained, the rats were then punished (with a delivery of shock) while they consumed the food (avoidance training). Over time, control animals increased their latency to enter the goal box, indicating a tendency to resolve the apparent approach-avoidance conflict with an avoidance response. In contrast, aspirative/electrolytic lesions of the HPC impaired the acquisition of passive avoidance behaviour, with the lesioned rats continuing to enter the goal box at the same latencies as during approach training, after the introduction of shock. Other studies also noted that HPC-lesioned rats were more resistant to extinction conditions, showing perseveration of runway or lever press responses that were no longer rewarded [15,17,36]. Niki